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This product is based primarily on aerial photograph interpretation with limited fieldwork. It has not yet been subjected to peer review and probably will be modified prior to final release. **Final versions of the map and report should be available on or about May 1, 2002.**

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The identification and location of landslide hazard areas are based on review of limited aerial photographs that are listed on each specific map. In most cases, only two sets of aerial photographs were used to construct the landslide and geomorphic features maps. Due to time constraints all available data were not necessarily reviewed and used in construction of these maps. The quality of data used is varied. The information depicted on the maps has been drawn as accurately as possible at 1:24,000-scale.

Information on the NCWAP maps and in the accompanying reports is not sufficient to serve as a substitute for site specific geologic and geotechnical site investigations as required under the Chapters 7.5 and 7.8 of Division 2 of the Public Resources Code.

Maps and reports on this website are the California Geological Survey's proposed contribution to the interagency North Coast Watersheds Assessment Program (NCWAP), which includes the following state agencies: California Geological Survey, Department of Fish and Game, California Department of Forestry and Fire Protection, Department of Water Resources, and the North Coast Regional Water Quality Control Board. The interagency NCWAP program provides a compilation of data and a process for analyzing information to characterize current and past watershed conditions. This program will cover approximately 6.5 million acres of private and state lands within the 12 million acre North Coast Hydrologic Region. Information will be used to guide watershed management and restoration planning, restoration and recovery planning for anadromous fisheries. Complete description of the interagency NCWAP can be found at www.ncwatershed.ca.gov.

REPORT OR THE
GEOLOGIC and GEOMORPHIC
CHARACTERISTICS
of the

GUALALA RIVER WATERSHED

By

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DEPARTMENT OF CONSERVATION
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Introduction

The Gualala River system and surrounding topography evolved in response to rapid geologic changes along the west coast of North America over the past 30 million years, and especially in the last five million years. The drainage networks evolved along with the changing landscape. The drainage network of the Gualala River is bedrock controlled and records the major geologic changes that took place. The landscape continues to change most notably by mass wasting. Mass wasting and erosion affect fluvial geomorphic conditions, which in turn affect aquatic habitat conditions. Many studies show a sequence of channel change and therefore habitat transformation in response to large punctuated sediment inputs (landsliding). The effects of landslide debris in channels include: 1) initial aggradation followed by incision, 2) initial fining of bed material followed by coarsening, 3) braiding of formerly single channel reaches, 4) decrease in the number of pools and concomitant increase in riffles followed by an increase in pool frequency and depth, and 5) terrace construction (Miller and Benda, 2000).

In the Gualala watershed, the distribution of landslides, channel types, and sediment are primarily controlled by distribution and physical properties of the various geologic formations that form the foundation of the watershed. Understanding those background relationships can aid in the identification of operative processes, such as channel change.

Over the past 5-20 million years, much of the region was uplifted. As it was raised and tilted, the rivers incised down to bedrock in many places. Large portions of the Gualala River system are incised into heterogeneous bedrock The bedrock is composed of several rock formations of very different properties that have been juxtaposed in a complicated pattern through multiple generations of folding, faulting, uplift, and subsidence –many of which remain evident in the topography. The resistance of the bedrock to erosion is extremely variable and depends in many ways on the rock composition and the degree of deformation. As the bedrock was uplifted, crushed, and redistributed along active faults, the Gualala River system concurrently evolved. The network of watercourses (Figure 1) followed paths of least resistance across the landscape as determined by the distribution of hard, durable rock versus soft, easily erodible rock Many watercourses lengthened favorably along the weakened rock within fault zones. Many of the streams in the Gualala watershed and surrounding area are clearly fault controlled. Most of the faults, with the exception of the San Andreas Fault and possibly the Tombs Creek and Mount Jackson Faults (for convenience in this report the closely spaced Mount Jackson and Tombs Creek Faults are combined as the Tombs Creek Fault Zone), are now dormant.

However, the landscape continues to actively change through the processes of erosion and mass wasting in ways that force the streams channels to continually adjust. The timescale over which these changes occur vary from years to millennia. The forces of erosion work aggressively against the weaker rock moving them down into the stream channels in the form of landslides. Streams erode into bedrock forming canyons and the local strength of the bedrock determines the steepness of the canyons. Over the long term, the canyon slopes steepen to a threshold at which there is quasi-equilibrium between continued steepening and mass wasting. For example, steep canyons form where bedrock is harder and resistant. But where uplift and incision outpaced mass wasting, the slopes can be oversteepened. Shallow landsliding is common in many of the steep canyons in the watershed as equilibrium is gradually established. In many areas, large landslides are obstacles that cause the streams to change course and grade. Even in areas where faulting and landsliding are dormant, the resultant distribution of varying rock types still determines stream channel processes. This paper describes in brief detail the relationship between bedrock structure, mass wasting, and the Gualala River system. The accompanying maps illustrate the distribution of the variety of rock formations, known faults, landslides, and predicted landslide potential.

Topography

The Gualala River drains 270 square miles along the coast of southern Mendocino and northern Sonoma Counties. The topography consists of steep slopes, moderate rolling hills, flat-topped hills, and marine terraces. Elevations range from sea level to 2,602 feet above sea level at Gube Mountain. Steep slopes are found throughout the watershed. The coastal and steeper inland areas are forested; whereas, the rolling hills are generally grassy. Drainage networks are largely fault controlled and vary from very long linear reaches (as along the Little North Fork and the South Fork) to regions of low ordered rectilinear patterns (as along Rockpile Creek) to high ordered, deranged convoluted patterns (as in the eastern Wheatfield Fork)(see Figure 1). The Gualala River watershed is elongated (about 32 miles long by 20 wide) such that the entire basin is within 20 miles of the ocean. A relatively straight and continuous ridgeline separates the Gualala River from the ocean (Figure 2). The river crosses the ridge in a saddle and flows northward to its mouth at the town of Gualala. The inland boundaries of the watershed and sub-basins are dominantly defined by a disconnected series of northwest oriented groups of ridges. Based on general geomorphology, the watershed is divisible into three distinctive regions; a northern, a central, and a western as exemplified by drainage patterns (Figure 1). A general geomorphologic description of these subdivisions is presented below.

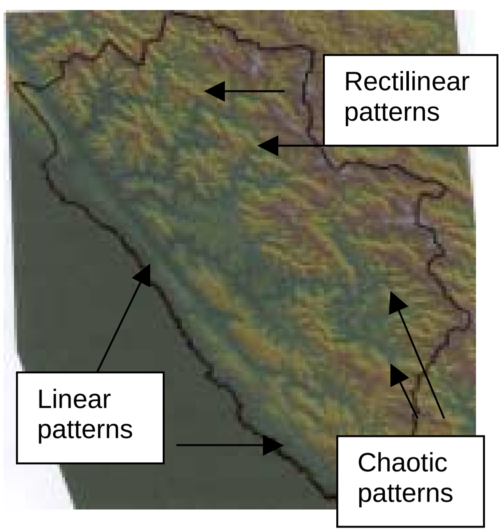

Figure 1: Triangular Integrated Network (TIN) image generated from 30-m DEM illustrates the complexity of drainage patterns in the Gualala River Watershed

Figure 2: View southward above South Fork of the Gualala River. The informally named Gualala Ridge separates the river from the Pacific Ocean as it flows within the rift zone of the San Andreas Fault. Note the low sinuosity of the river.

Geologic setting

Rock Formations

The geologic map illustrates many geologic units within the Gualala Watershed (see attached Plates showing Geologic and Geomorphic Features Related to Landsliding. Gualala River Watershed): 1). The vast majority of the Gualala watershed is underlain by the Franciscan Assemblage. Blake and others (1984) subdivided the Franciscan Assemblage into four fault-bounded terranes; Rio Nido, Pickett Peak, Coastal Belt, and Central Belt. In general, the terranes of the Franciscan Assemblage have been variably fractured, faulted and folded by tectonic processes associated regional uplifting and transpression. The rocks were formed in the accretionary prism that developed within the subduction zone between North American and Pacific Plates during the Mesozoic. The terranes were accreted to the leading edge of the North American Plate prior to the deposition of the overlying Pliocene Ohlson Ranch Formation. These tectonic processes have weakened the Franciscan Assemblage, contributing to landsliding and debris flows. The Franciscan Assemblage and the Ohlson Ranch Formation are the most important geologic units in regard to landsliding in the Gualala watershed. Their lithology and relative slope stability are described below.

Rio Nido Terrane

The late Cretaceous-aged Rio Nido terrane of the Franciscan Assemblage (TKfs) extends in a Northwest orientated belt along the west side of the Tombs Creek Fault Zone (Huffman and Armstrong, 1980, and Blake, Howell and Jayko, 1984). This unit generally consists of massively bedded, medium-grained, graywacke with interbedded siltstone, shale and conglomerate. Much of this unit is locally fractured, with the tectonic deformation obscuring the original structure. Within the Rio Nido terrane, the penetrative fractures within the Rio Nido rocks are often annealed and the general structure is massive and hard. Fresh sandstone is hard, but weathered portions are firm to hard. The sandstone is fine to medium grained, dark gray where fresh, light brown where weathered, and moderately hard to hard. Bedding, where present, is up to five feet thick and the fracture spacing was closely to very closely-spaced. In general, the Rio Nido terrane has been variably fractured, faulted and folded by tectonic processes associated regional uplifting and transpression. Many active earthflows are found in association with this formation in Gualala watershed.

Pickett Peak Terrane

The early Cretaceous-aged Pickett Peak terrane (KJfm, KJfss) of the Franciscan Assemblage forms a belt adjacent to and in some places across the Rio Nido terrane. The Pickett Peak terrane underlies the area northeast of the Tombs Creek Fault Zone. The Pickett Peak terrane consists of a melange of clayey gouge with severely sheared blocks and small shattered masses of metamorphic semischistose meta-graywacke, meta-shale, and meta greenstone. Blocks have a diameter of >100-feet and the shattered masses are as much as 0.1 to 0.2 miles in length, and together constitute about half of the units mass. Gouge and the severely sheared masses are firm to soft, lack bedding and are very closely fractured. Blocks are typically hard, have moderate to widely spaced fractures, bedding is thick to thin in the meta-graywacke. Many large active earthflow complexes are found in association with this formation in Gualala watershed.

Coastal Belt Terrane

Late Jurassic to early Cretaceous aged Coastal Belt of the Franciscan Assemblage (KJFs, Kfgs) underlies the vast majority of the Gualala watershed. The unit predominantly consists of graywacke type sandstone and shale with minor greenstone, conglomerate, chert and limestone (Blake, Smith, Wentworth, and Wright, 1971; Huffman and Armstrong, 1980; Wagner and Bortugno, 1982; Ellen, and Wentworth, 1995). The sandstone is generally massive to locally thin-bedded. Much of this unit is unsheared whereas other portions are severely sheared and may contain hard blocks. Fresh sandstone is hard, but weathered portions are firm to hard. This formation forms steep slopes throughout the McGuire Ridge quadrangle and on Oak Ridge and Fuller Mountain in the Annapolis quadrangle. However the topography is more subdued in the southern areas of occurrence. Where steep, debris slides and debris flows are common. Large dormant translational/rotational rockslides are also common.

Central Belt Terrane

The late Jurassic to early Cretaceous aged Central Belt of the Franciscan Assemblage (Huffman and Armstrong, 1980) interfingers with the Coastal Belt in the southern portions of the watershed. The Central Belt consists largely of a melange of variably abundant hard, resistant blocks and small shattered masses of chert, “high grade” metamorphic rocks, sandstone, greenstone, metagreenstone and serpentinite suspended in sheared shale and sandstone gouge matrix. Discrete blocks range in size from less than one foot to greater than 5 miles. This sandstone is medium-grained, moderately to thickly bedded, moderately hard and strong, gray where fresh and light brown where weathered. Many active earthflows are found in association with this formation in Gualala watershed. This strong relationship is further discussed and illustrated below in the Mass Wasting History section.

Ohlson Ranch Formation

The Pliocene Ohlson Ranch Formation caps flat to slightly undulating ridge tops found extensively throughout the Annapolis and Stewarts Point 7.5’ quadrangles. This geologic unit consists mostly of poorly consolidated marine sandstone, with small exposures of conglomerate. The Ohlson Ranch Formation is deeply weathered and is generally soft, and the sandstones are very fine-grained. The sediments were deposited on marine terrace surfaces that later were uplifted by regional tectonic forces. This unit is generally less than 100 feet thick. Limited fieldwork and map relations suggest that failures occur primarily where slopes steepen along stream channels and at the edges of the flat-topped ridges. This relationship is further discussed and illustrated below in the Mass Wasting History section. Failures occur primarily as small discrete slumps, rotational slides, and earthflows.

Structural evolution

The northern coast of California evolved dramatically over the last 23 million years in response to changes in the convergence of the Pacific and North American Plates (Atwater, 1989). This major plate reorganization changed coastal conditions throughout the circum-Pacific and coincided with, if not created the opportunity for, the evolution of the five species of Pacific Salmon (Montgomery, 2000). The entire Coast Ranges of California became profoundly affected by a broad, extensive system of strike-slip faults known collectively as the San Andreas Fault System.

The Gualala River watershed resides wholly in the San Andreas Fault System and is bounded on the west and east by the San Andreas and the Maacama Faults respectively (see Figure 3). The Maacama Fault lies about 25 miles east of the watershed. Both faults are active, sub-parallel, right lateral strike-slip faults. Latest ground movements in the vicinity along the San Andreas Fault occurred in 1906 with San Francisco Earthquake. Near Fort Ross, ground was displaced right laterally up to 12 feet and uplifted 3 feet. Along the South Fork of the Gualala River numerous landslides occurred and entered the river (Lawson, 1908). The Maacama Fault is actively creeping and has generated many low magnitude earthquakes. The area around the Clear Lake volcanic field, less than 40 miles east of the Gualala River basin, is also seismically active. Many inactive faults crisscross the region between the San Andreas and Maacama Faults. The dominant trend of these inactive faults is sub-parallel to the San Andreas Fault. Many show a history of strike-slip movement and are considered a part of the San Andreas Fault System. The rocks across this entire zone are generally intensely sheared, a contributing factor in their instability.

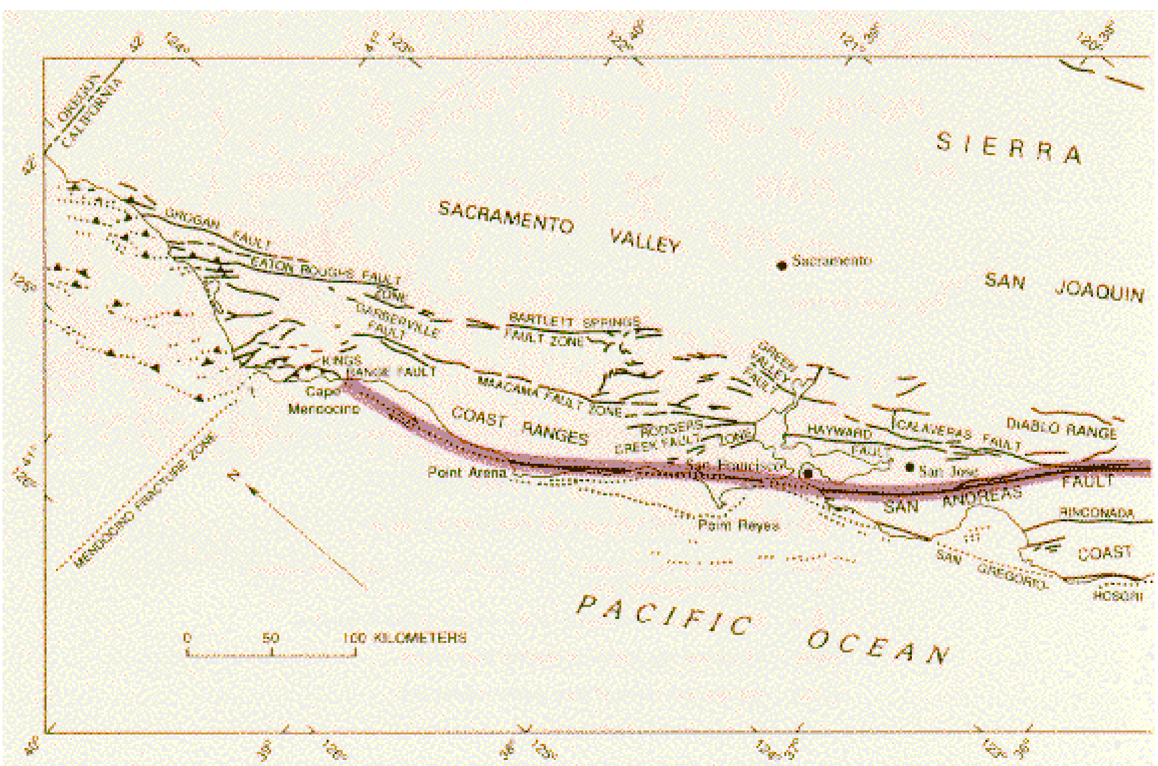

Figure 3: Map of northern San Andreas Fault System. The Gualala River watershed occupies the area between Points Arena and Reyes and between the Maacama Fault and the coast. Image from USGS Professional Paper 1515.

The drainage of the Gualala River follows a complex course strongly controlled by the geologic history of the basin development. Much of the Gualala River follows narrow, linear depressions that probably restrict the river from freely meandering. Some of the linear depressions are clearly fault controlled; with others the association is vague. Isolated patches of the fluvial conglomerate member of the Ohslon Ranch Formation are remnants of the drainage system that existed prior to deformation starting in the Pliocene (5 million years ago) (see attached Plates showing Geologic and Geomorphic Features Related to Landsliding. Gualala River Watershed). Many of the modern streams developed during deformation. That deformation includes the complex and on-going development of the San Andreas Fault System: such as, subsidence of pull-apart basins, uplift of compression ridges, and lateral translation of topography. The channels deeply incised into the topography, especially along fault zones, developing a legacy that controls active stream channel geomorphology and sedimentation (i.e. current fluvial conditions).

Gualala Watershed Evolution

For the Gualala region, the major consequences of the global scale tectonic changes were: 1) the strike-slip faulting and 2) at least two cycles of uplift and subsidence beginning about 5 million years ago. Three of the strike-slip faults are the active San Andreas Fault and the Quaternary Tombs Creek and Mount Jackson Faults (Huffman and Armstrong, 1984). This rapid evolution is not unique. Basins formed by strike-slip faulting can be developed and destroyed during plate boundary evolution on a time scale of 10,000-1,000,000 years (Barnes and others, 2001). Similarly, much of the modern topography in the Clear Lake area formed about the same time also in response to the development of the San Andreas Fault System. There, more details studies show that during the last 2 million years, two major episodes of basin deformation occurred. The first is initiated about 1.5 million years; and the second began about 600,000 years ago (Sims, 1988 and references therein).

The San Andreas Fault probably formed the valley in which the Little North and the South Forks of the Gualala River now flow. The Tombs Creek Fault Zone deflects Osser Creek, Flat Ridge Creek, and the Wheatfield Fork of the Gualala River (Figure 4). The construction of the basins and ridges was probably concurrent with, and a consequence of, the activity of these and several other faults. Gualala drainage has evolved along with the landscape. Faulting and folding disrupted the prevailing drainage, which has re-established multiple times.

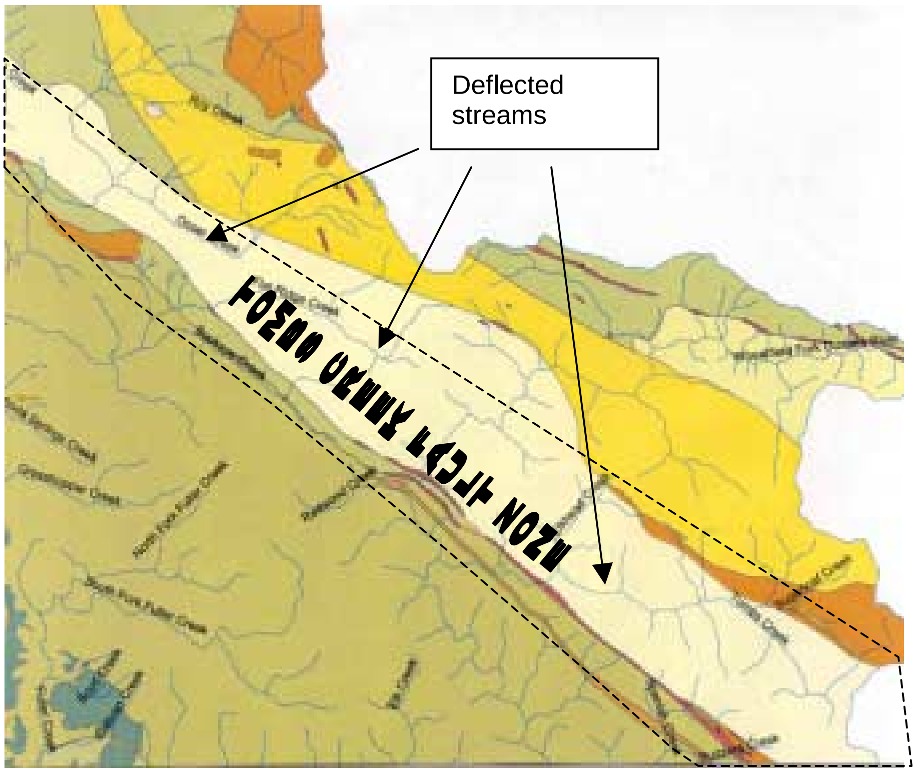

Figure 4: Detail geologic map showing stream deflection along the Tombs Creek Fault

The imprint of deformation on the landscape in this region has been the subject of several geologic studies. Lawson (1894) proposed that prior to deformation the landscape consisted of a broad, gently sloping, low relief landscape with large, low gradient meandering streams. He called this region the Mendocino Plateau, which since has been deformed, uplifted, and deeply incised. More recent studies have investigated the stream channel patterns to determine deformational history. Prentice (1989) and Gaudemer et. al. (1989) described the complex lateral response of the stream channels to tectonic disruption in the Gualala River Watershed. In fact Prentice proposed that the Gualala River once drained through the mouth of the Garcia River to the north, i.e. the Gualala and Garcia River systems originated as one (see Figure 5). Across the divide in the Navarro River and Rancheria Creek watersheds, Manson (pers. comm. 2000) described similar repeated cycles of stream capture and beheading.

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The Gualala River watershed developed through a series of subsidence and uplift probably associated with the strike-slip faulting. The subsidence and uplift was not a simple up and down episode, but varied in different parts of the watershed. As areas subsided, other areas were uplifted. Similar associations are found all along the length of the San Andreas Fault. In the Gualala region, the central portion of the watershed subsided and was sub-marine as recently as Pliocene (5 million years ago). The Pliocene sediments are now elevated up to 800 feet above sea level within a couple miles of the ocean. This basin probably formed as a pull-apart basin stretched by divergent motions of paired strike-slip faults. The gravelly, silty, and sandy Ohlson Ranch Formation was deposited into the basin and is found capping many flat-topped ridges located throughout the Annapolis and Stewarts Point 7.5 minute quadrangles.

Localized uplift is further recognized in the area of Gube and Snook Mountains and in the area of Morhardt and Kings Ridges. These uplifted areas are parallel, similar sized blocks that appear to be structurally alike.

These twinned uplifts are tentatively interpreted as compression ridges that, in an opposite sense to pull-apart basins, formed where convergent motions between paired strike-slip faults caused local compression. Fluvial conglomerate along Kings Ridge at an elevation of approximately 1,600 feet above sea level reveals the last vestiges of a fossil river that presumably flowed from the south into the pull-apart basin. No headwaters are recognized for this river. This indicates significant subsequent uplift. Similarly, the formation of the northern compression ridge (the current watershed divide) cut-off another significant fossil river that had flowed from the northeast into the basin through the area around Flat and Bear Ridges as revealed by fluvial sediments there (Higgins, 1960). The emerging ridge in the north apparently became the divide and diverted the drainage from the northeast to what is now the Russian River watershed. Subsequent strike-slip faulting appears to have created right lateral offset of the compression ridge in several places as seen in abrupt jogs in the northern watershed boundary.

Significance of Sea Level Changes

Sea level has fluctuated in response to global climatic changes. Sea level changes during the Pleistocene occurred in response to a series of glaciations (ice ages) and interglacials. Prodigious volumes of sea water were locked in glaciers at times in the past; thus lowering the sea level. During the latest marine low stand, 15,000 years ago, -the Wisconsin Glaciation -sea level had fallen to a maximum of 390 feet (120m) (Grove and Niemi, 1999). The rivers incised in response to falling sea level. During interglacials sea levels rose and at times were higher than present. Currently global warming is resulting in sea level rise.

The sea level rise, beginning 125,000 years ago, flooded the river valleys that gradually filled with sediment and created a distribution of alluvium similar to current conditions along the North Fork Gualala, Rockpile Creek and Buckeye Creek as illustrated in Figure 6.

The drop in sea level caused the rivers to incise and excavate accumulated sediment. The extent of this incision can be estimated by projecting the slope angle of the valley walls into the subsurface. Near the mouth of NF, this indicates that bedrock and the ancestral valley floor may have been 220 feet below modern MSL. Similarly, the elevation of the bedrock valley floor of the Russian River was interpreted at minus 200 feet below current MSL (Higgins, 1950). Additionally, a submerged marine terrace off the Sonoma coast formed, during the Wisconsin Glaciation, and is 200 feet below sea level (Bauer, 1952).

Similar records of incision and valley filling are found in other California coastal rivers. Some well logs show a fining upward sequence in the valley fill, indicating progressive decrease in gradient and river competence as the valleys filled with alluvium to present levels following subsequent sea level rise.

Thus; the NF may be underlain with a 200 feet thick, fining-upward sequence of alluvium that was deposited during the last 15,000 years at an approximate rate of 0.013feet/year. As in other coastal streams, the alluvial fill probably fines upward from boulders at the basal conglomerate to gravel at the modern surface. These processes are expected to continue due to global warming and may result in continued fining of the streambed.

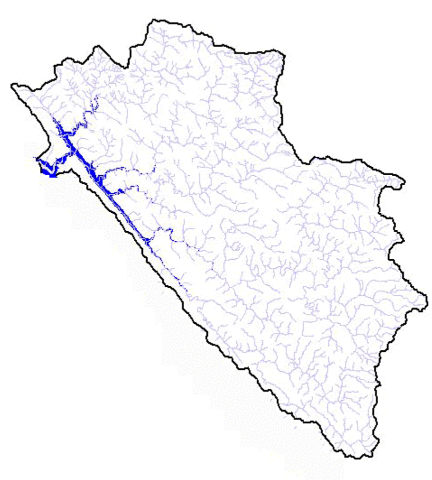

Figure 6: High stand sea level at 125,000 years ago in the Gualala Watershed. Dark blue represents area inundated with rising sea levels at 125,000 years before present. Light blue lines represent modern streams.

Geomorphic subdivisions

As discussed above, the watershed is divisible into three distinctive geomorphic subdivisions; a northern, a central, and a western (see Figure 7). Profound differences in 1) drainage patterns, 2) steepness, and 3) overall orientation of the ridges and streams make these subdivisions distinct. These younger (Paleogene-Recent) subdivisions differ from the older (Late Mesozoic) terranes of Blake and others, 1984.

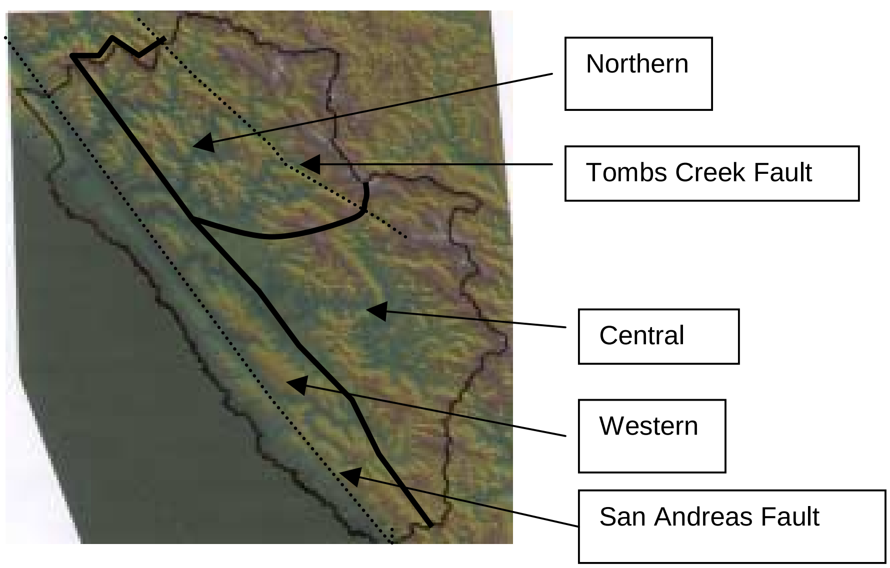

Figure 7: Map showing geomorphic subdivisions. Boundary locations are not rigidly defined and may be more diffuse than illustrated. For example, the western edge of the Northern subdivision is overprinted by the younger topography related to the San Andreas Fault.

Northern subdivision

The northern region is distinct because it is 1) occupied by rectilinear, low-ordered drainages such as Rockpile Creek and the North Fork of the Gualala River, 2) is underlain with the Coastal Belt of the Franciscan Formation, and 3) contains the steepest slopes in the watershed. The geologic history and these immature geomorphic conditions imply that this subdivision was uplifted above sea level more recently than the remainder of the watershed. In addition to recent uplift, the western portion of this area has subsided creating a low region at the confluence of Rockpile Creek and the North Fork. The drainage networks of the North Fork, Rockpile Creek, and Buckeye Creek all in a general sense drain radially toward the low region which the drainages of Little North Fork, Robinson Creek (Figure 8). A series of NW trending strike-slip faults have offset drainages in a uniform manner forming "twinned" drainage networks in the Rockpile Creek and North Fork Gualala River sub-basins. Tributaries join trunk streams orthogonally producing a zig-zag pattern with a strong NNW orientated fabric. Secondary tributaries that flow westward across the regional NNW grain are far more numerous and longer than those that flow eastward across the grain, indicating westward tilting.

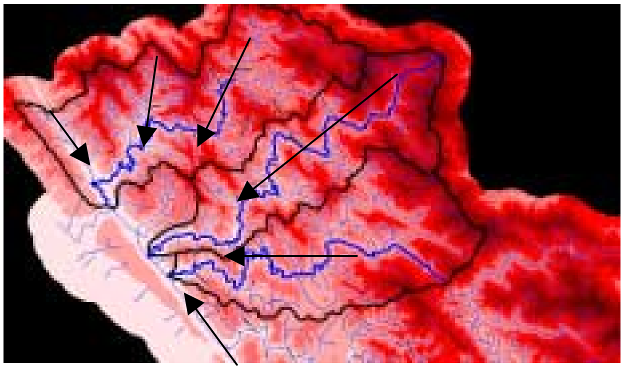

Figure 8: Digital elevation model showing the general radial drainage pattern. From a 11:00 position moving clockwise, the major drainages are the Little North Fork, Stewart Creek, North Fork, RockPile Creek, and Buckeye Creeks. Darker shades indicate higher topography.

The formation in this region, although broken (tectonically crushed but not significantly sheared), forms steep slopes and is relatively more stable and coherent (bedding is recognizable) than it is in the rest of the watershed. However, slopes failures are common and occur dominantly as debris slides and flows (Figure 9).

Figure 9: Photo series of a debris flow in the McGuire Ridge Quadrangle. From left to right, photos show the debris flow across the river, a close-up of the torrent track, and its deposit along the riverside road. Note the truck for scale. Photos by Mike Fuller and Wayne Haydon.

Central subdivision

The central subdivision has experienced the most complex history of deformation and drainage. This subdivision extends almost from the Gube Mountain area southward to Fort Ross and comprises most of the watershed. The youngest consolidated geologic formation in this subdivision is the Ohlson Ranch Formation. The relatively young marine sediments of this formation are poorly consolidated sands, silts, and gravels that tend to slump or flow when saturated on slopes such as those near the contact with the underlying Franciscan Formation. In the central subdivision, the Central Belt Franciscan generally flanks the Coastal Belt, except in the Fort Ross quadrangle where complex faulting has shuffled both belts. The Central Belt is largely a tectonic mélange (tectonically crushed and highly sheared rock) of generally resistant hard blocks in a weak fine-grained matrix and forms slopes mantled with creeping colluvium and deeper earthflows. Many deep-seated rockslides also occur; some appear to be intermittently active. The blocks consist of serpentinite, metacehert, and metavolcanic rock. Serpentinite, however, is especially prone to deep-seated and shallow failure. Hard metavolcanic blocks form bold outcrops that dot the landscape. The topography is rounded and grasslands are common. Figures 10a, 10b, and 10c are a series of photographs taken from Oak Mountain showing the topography of the Central subdivision.

Figure 10a (see explanation below photo 9c)

Figure 10b (see explanation below photo 9c)

Figure 10c

Figures 10a, 10b, and 10c: Photo series from Oak Mountain showing topography of the Central subdivision. Views are looking northwest (10a), north (10b), and west (10c). Note hummocky slopes, gullies, and earthflows.

Along the Wheatfield Fork of the Gualala River, large horizontal movements on NW-WNW strike-slip faults stretched out many of the streams along the faults even to the point of detachment from their headwaters in a process generally illustrated in Figure 11. Abandoned headwaters were blocked until finding favorable passage (typically an abandoned trunk stream) around obstacles. Slip along the strike-slip faults caused the west side to move relatively northward.

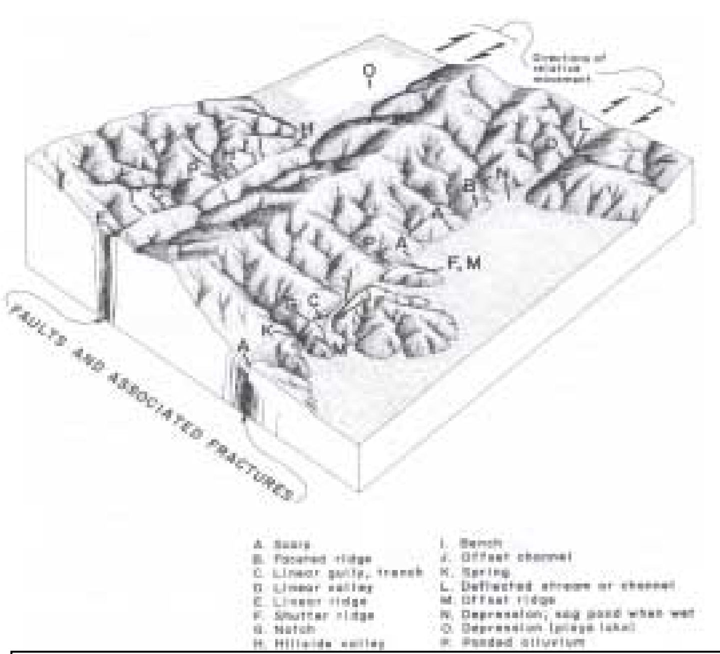

Figure 11: Schematic diagram illustrating the origin of various tectonic geomorphic features typical of the region.

For example, drainage is diverted southward along the east side of Oak Mountain. On the west face of Oak Mountain is the upper Fuller Creek watershed. The main forks of Fuller Creek appear to be the beheaded remnants of a former drainage that may have originally flowed across the Oak Mountain area. The northwestward translation or uplift along the Tombs Creek Fault Zone and ancillary faults likely placed Oak Ridge in its current position that blocks drainage from the east (Figure 12).

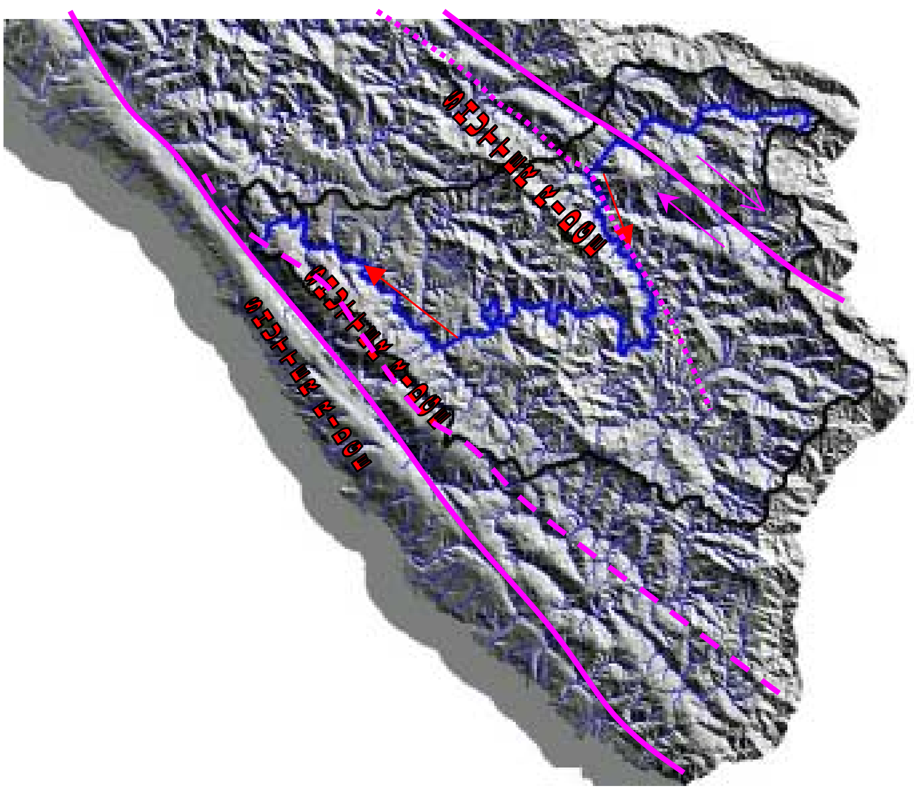

Figure 12: Diversions of the Wheatfield Fork. Parallel shutter ridges translated northward along parallel faults divert drainage. The shutter ridges shunt drainage along their NW trending, east facing range fronts.

In several areas, streams that cross strike-slip faults follow abrupt deflections along the fault zone. This indicates co-development of stream and fault. Osser and Flat Ridge Creeks are two examples. The amount of stream deflection across a fault is related to many factors including channel age relative to fault activity. Generally, diverted streams that existed prior to faulting will show the greatest offset and the youngest streams the least offset. Some profound age differences are evident in the Wheatfield Fork sub-basin and record a complex chronology of deformation and fluvial response. As a result of the multiple deformations, the complicated drainage pattern in this region developed high order networks.

Western subdivision

In the western subdivision, the drainage network is dominated by the San Andreas Fault. Stream beheading, capture, and blockage by ridges are common and were a focus of a study by Prentice (1989). She concluded that through those processes an earlier single drainage system transformed into both the modern Gualala and Garcia Rivers. While migrating northwesterly, the informally named Gualala Ridge in the German Rancho progressively blocked the drainage of the South Fork of the Gualala River, then the Wheatfield Fork of the Gualala River; such that the river now flows northward along the fault until reaching an outlet at the town of Gualala (refer back to Figure 5). Within the San Andreas Fault Zone, the divide between the Little North Fork Gualala and South Fork Garcia Rivers is a gentle 350-foot rise, largely composed of coalesced landslides (Plate 1). However, the divide is dominantly defined by the more broadly elevated surrounding area.

In general, the valley walls along the San Andreas Fault are moderate to steep, benched and show a complex history of seismic deformation and abundant landsliding. Different rock units occur on either side of the fault with the Coastal Belt Franciscan on the east and the German Rancho and Gualala Formations on the west. Moderate to large relic landslides are abundant and small active landslides are common on both sides of the valley. In several areas, numerous landslide and fault features overlap into a dense pattern that cannot be reasonably illustrated at the scale of the attached Plates showing Geologic and Geomorphic Features Related to Landsliding in the Gualala River Watershed, and are mapped as composite slide slopes. Debris slides and debris flows are especially common near the San Andreas Fault where topography exhibits well defined benches and "lumps."(Figure 13).

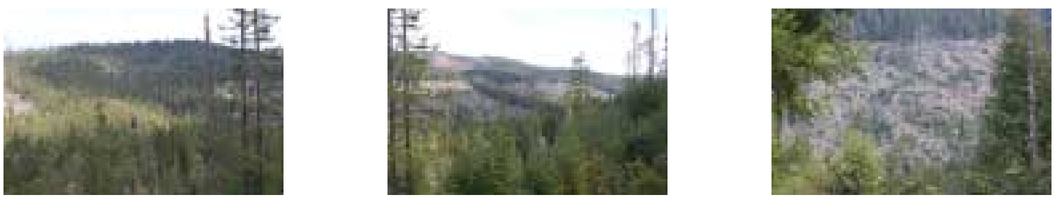

Figure 13: Photo series showing terrain of western subdivision. Note dominant midslope bench in middle photo and mounded ground in close-up photo of clearcut area in right photo.

Mass wasting history

Large numbers of debris slides and debris flows typically occur in response to major, high rainfall storms. Dormant deep-seated landslides, such as earthflows and translational/rotational slides, can be reactivated under such conditions. The slides are triggered by vigorous bank erosion and saturation of, or increased pore pressure within, loose hillside rock and colluvium. In general, review of aerial photography taken within a few years of major storms will reveal a plethora of recent landslides that can be attributed to the storm. The distribution and severity of the landsliding can vary within the watershed. This may be due to local variations of storm intensity, duration, or geologic and land-use conditions. Detailed evaluation of these factors is well beyond the scope of this geology report. The landslide distribution is illustrated on the accompanying Plates (Geologic and Geomorphic Features Related to Landsliding. Gualala River Watershed) and are described below.

However, based on unpublished information provided from California Division of Forestry and Fire Protection, the storm of 1964 was the most significant for the Gualala River watershed in terms of sediment delivery to watercourses. The decade prior was one of intense logging with construction of roads, skid trails, and landings in streams and along very steep slopes with no regard to erosion control and slope stability. The storm triggered landsliding of large volumes of sediment that resulted in the aggradation of many stream reaches. Many of these failed areas have not been repaired. The extent of their impact today is not well known. In the Fuller Creek sub-basin, subsequent storms resulted in less sediment delivery. This may indicate that the 1964 storm washed the majority of unstable material off the slopes and down the watercourses leaving little available for subsequent storms (Pacific Watersheds Associates, 1996). However, considerable volumes of unstable materials are available for accelerated mass wasting. Landsliding was abundant in Buckeye Creek during the 1964 storm as well as during subsequent major storms.

In steep terrain, the majority of the recent landslides are shallow failures. Because of high water content and gravitational energy, there is a high potential for delivery of debris to watercourses. In areas of moderate slopes with more cohesive material, deep-seated translational/rotational landslides become more significant, although debris flows and gullying are also important (Figure 14).

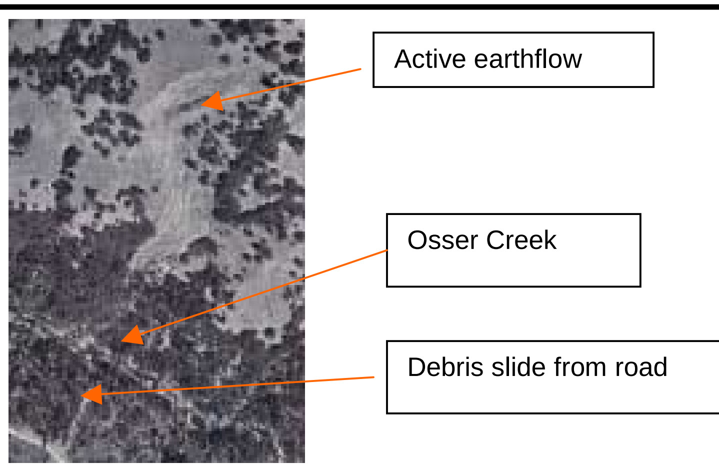

Figure 14: Aerial photo of an active earthflow and road-related debris slide taken one year after the 1964 storm. Either slide may have delivered sediment into the creek.

The material composition of a landslide is the primary determinant of what is delivered to the watercourses. Rock slides of hard, blocky rock with little soil deliver coarse material, i.e. boulders, cobbles, and gravels, which can persist in the channel due to their resistance to hydraulic erosion and transport. Stream flows can effectively cleaned-out fines that may have been delivered leaving a lag deposit of coarse and durable rock The deposit can add structure and complexity to the channel habitat. Large deep-seated slides consisting of primarily fine-grained material likely deliver fines to stream channels. The stream will flush the landslide debris but also may be overwhelmed if great volumes of material reach the channel. Flushed fines accumulate downstream where deposition is favored and may cause embeddedness of fish spawning gravels, aggradation, and channel braiding. Consequently, the impact of slides on streams may be either beneficial or deleterious to fisheries depending on specific conditions. These conditions can be somewhat predicted with an understanding of the underlying geology.

Historically active landslides were mapped from aerial photos based on the presence of fresh features or evidence of historic damage (i.e., damaged vegetation or man-made structures). In this report, the evaluation of the historical record is limited in that no photos older than 1984 were used for the landslide mapping. Therefore, the immediate effects of the 1964 storm and other important storms were not observed. Although historically recent effects could be observed in the 1984 aerial photographs, it was not possible to ascribe them to any particular storm or event. Comparisons of the historically active landslides mapped by CDMG from the 1984 and 1999/2000 aerial photos with those mapped by outside parties using other photography revealed the following generalizations. (Specific examples cannot be offered because of proprietary concerns and differences in data collection methods.) First, storm related landsliding was significantly more apparent in photos taken shortly after the event. The detection of those slides diminished in time as vegetation recovered and fresh geomorphic features faded. Secondly, individual sub-basins responded variably to different storms and the effects of any single storm were not evenly distributed throughout the Gualala River watershed. The examination of additional sets of aerial photography would undoubtedly show more of the historic landslide and stream conditions in the watershed and clarify patterns of response to perturbation.

Many large relic and dormant slides throughout the watershed remain important in the landscape. Some of these may be historic and others may be thousands of years old. Within that time span the climate was significantly wetter and cooler, geologic uplift rates were considerably more rapid, and earthquakes were probably more common. Paleoclimatic information derived from cores in Clear Lake and approximately 20 miles off the coast from Fort Ross are consistent with other regional studies and show that precipitation was at least 2.5-3 times greater during the Pleistocene (Adam and West, 1983; Adam, 1988,Gardner and others, 1988). All of these factors could have triggered the formation of many of the dormant old landslides. These dormant features have been highly eroded which occasionally makes recognition questionable. The size distribution of relic slides is probably skewed toward larger features because the long history of erosion has obliterated signs of the smaller features. Relic slides are important today because they influence modern stream and hillslope processes. For example, they continue to influence stream channel planform and profile due to their effect on the distribution of hard versus soft and erodible material. Massive ancient landslides on the flanks of Oak Ridge define the path of major tributaries. The drainage network of the North and South Forks of Fuller Creek is strongly influenced by ancient features (Figure 15). Ancient landslides on the east flank of Oak Ridge caused realignment of the Wheatfield Fork (Figure 16). Additionally, many smaller, historically active landslides occur within or adjacent to relic slides and reactivation of the relic slide remains possible.

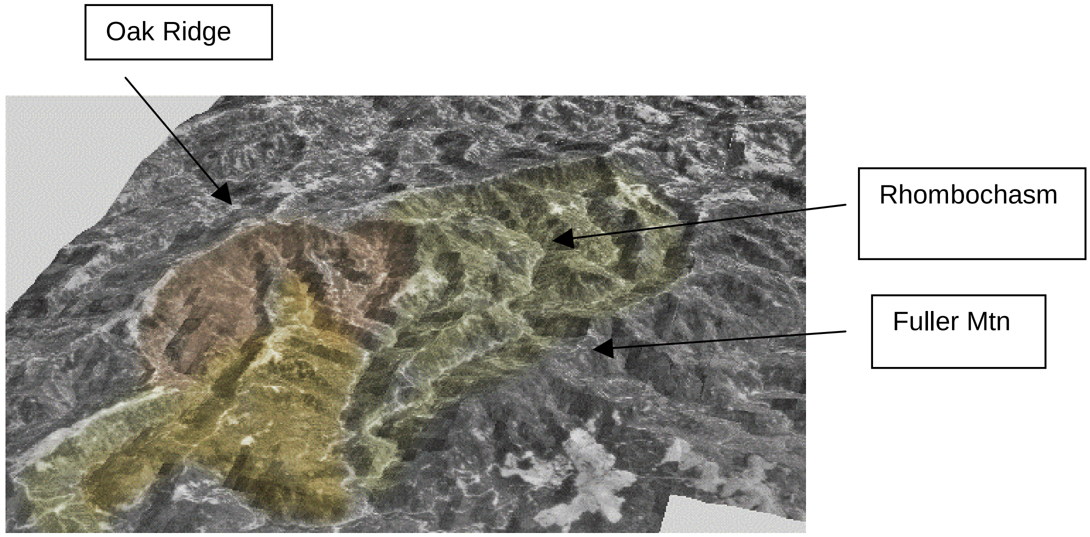

Figure 15: View southeastward at Oak Ridge. The west face of Oak Ridge is highly deformed and is tentatively interpreted as pull-apart rhombochasm (green highlight). A large ancient landslide (yellow highlight) collapsed into the rhombochasm leaving a bowl (brown highlight) in the side of the ridge. The remainder o the rhombochasm may be occupied by older, less recognizable landslide deposits. Image is digitally enhanced aerial photos.

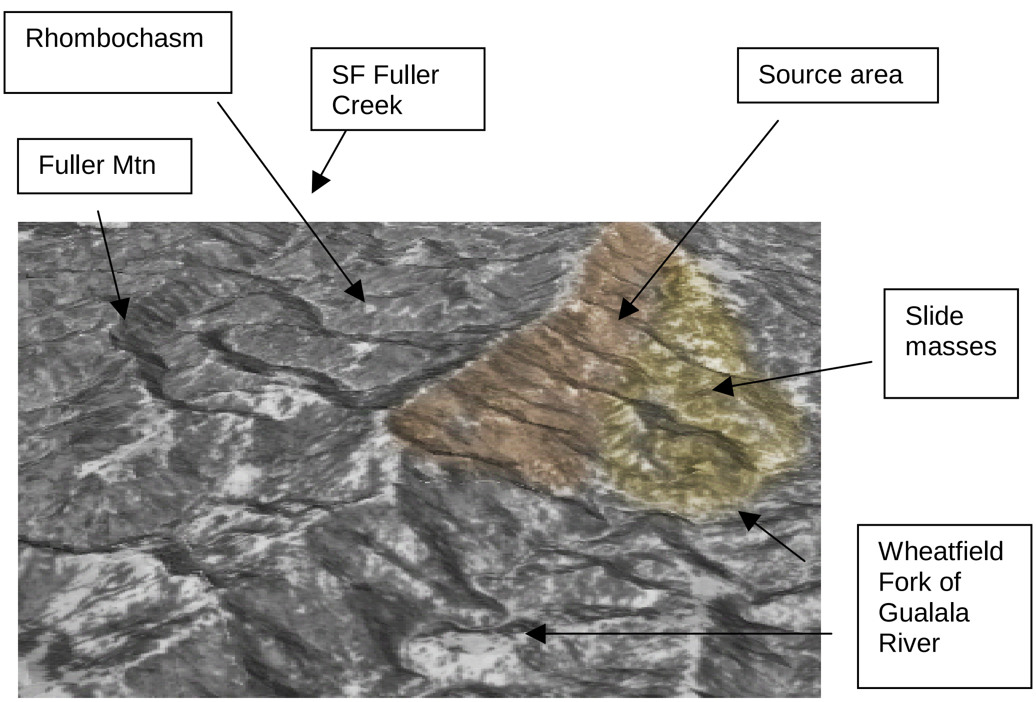

Figure 16: NW view above Oak Ridge of ancient landslides shed from east face of ridge. Wheatfield Fork of the Gualala River is seen winding its way from upper right hand corner of image southward along flanks of slide masses. On left side of image, three concentric drainages within the rhombochasm merge into the South Fork of Fuller Creek and flow northward. The ridgelines of Fuller Mtn and Oak Ridge form semiparallel borders to rhombochasm marked with the trio concentric ridges and valleys. Image is digitally enhanced aerial photos.

Younger dormant landslides were identified based on an overall more juvenile appearance and appear scattered throughout the Gualala watershed but follow the same distribution pattern of historically active slides. Again, due to the effects of continued erosion, there may be a detection bias toward larger features.

Historically active landslides occur throughout the Gualala River Watershed. The accompanying Plates showing Geologic and Geomorphic Features Related to Landsliding in the Gualala River Watershed are at a scale of 1:48,000. Landslides as large as a fifth acre are mapped as single points; those larger are mapped as polygonal areas. The distribution of historically active landslides in the watershed can be broken down to illustrate its dependence on three factors; lithology, slope, and stream action. Topography is the consequence of the interactions all three factors. The following maps show the spatial relationships between active landslides and lithology (Figures 16 and 17).

The Central Belt of the Franciscan Complex consists of weak rock and large landslide complexes can form therein. There is high correlation between active slides and this rock.

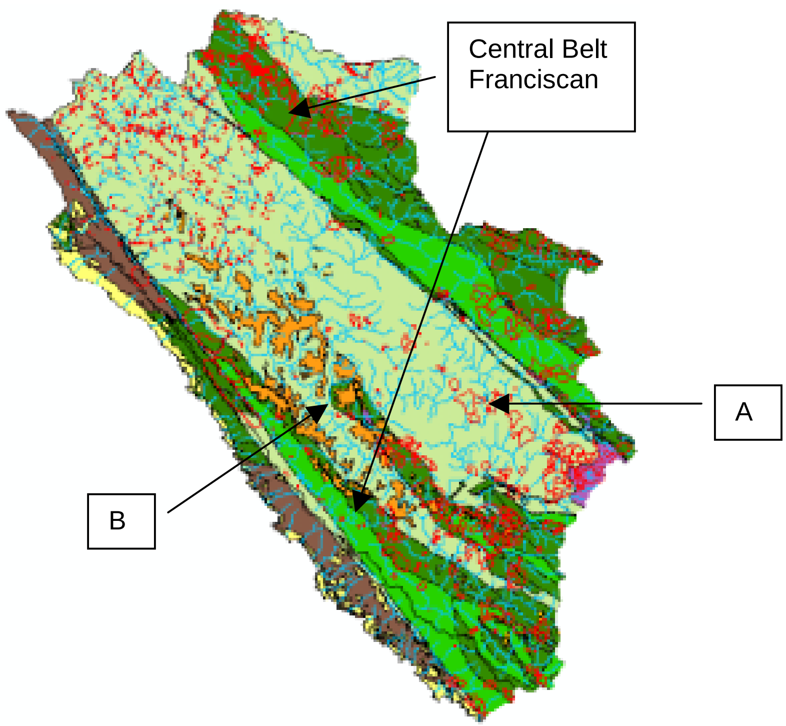

Figure 16:Geologic map overlain with large active landslides (red polygons). Note the high correlation of large landslides with the Central Belt of the Franciscan Formation (shown in darker greens). Arrow A refers to a Northwest trending string of large landslides that do not seem to correlate with the Central Belt. However, this string does follow disrupted topography that has been tentatively interpreted, based on other criteria, as a shear zone. Figure 15 zooms into the area indicated by Arrow B.

The Ohlson Ranch Formation is poorly consolidated weak rock that sits atop flat-topped ridges found throughout the Annapolis Quadrangle and adjoining areas. The Ohlson Ranch Formation is stable on relatively flat slopes, but is unstable on steeper slopes generally occurring along its contact with underlying formations and along stream channels.

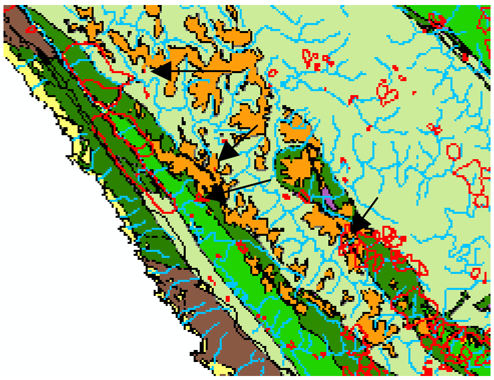

Figure 17: Geologic Map overlain with active landslides.
The Ohlson Ranch Formation is shown as orange. Historically active landslides are shown as re polygons. Black arrows show the occurrence of landslides along the margins of the Ohlson Ranch Formation.

Certain portions in the Gualala River Watershed are more active in terms landslides and have a higher potential of future landsliding. These are represented in Plate 2: Landslide Potential Map. A simplified version of the potential map is illustrated in Figure 18. The distribution of active landslides and landslide potential in the watershed is described in further detail below. The impacts of the landslides on stream conditions are considered in the Fluvial Geomorphology section of this report.

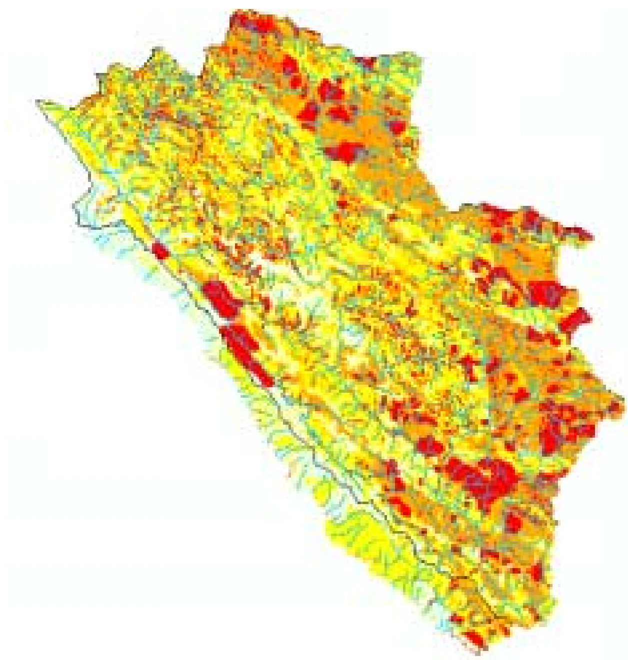

Figure 18: Landslide Potential Map with streams. The colors indicate landslide potential ranked from highest to lowest as follows: red, orange, brown, and yellow.

The areas of high landslide potential are probably areas of long-term sediment sources that may impact stream habitat.

Summary of Mass Wasting Conditions

Very large dormant rotational/translational landslides are found in the following areas:

Along the San Andreas Fault Zone

Along the Tombs Creek Fault Zone and Oak Ridge

Very large active and dormant earthflow complexes are found in the following areas:

Within or partly within the Central Belt Franciscan Fm.

Debris Slides are found in the following areas:

Steep terrain with incised streams – NF, SF, Wheatfield, Buckeye, Rockpile, Fuller Creeks -road cuts and fills. These are especially abundant in the NF basin on the steepest slopes in watershed.

Debris flows are found in

Moderate-steep terrain –prominent in NF Fuller Creek, NF and SF Gualala -road cuts and fills. These are especially abundant in the NF basin on the steepest slopes in watershed.

Inner Gorges are found in:

Scattered stretches along incised streams, SF, NF-Gualala, Buckeye and Rockpile, Haupt, and Fuller Creeks.

Complex slide slopes are found in:

Areas of high landslide activity where many active slides overlap and merge on top of and over dormant slides. The entire area is complex and would require site-specific geologic evaluation to determine the stability of land-use alterations. _- Found on Squaw Rock above Billings Creek, Oak Mountain and Black Oak Ridge above Tombs Creek; and along the Beatty and Miller Ridges above SF-Gualala.

Gullies are found in:

Areas of disturbed drainage regimes. Disturbance varies from 1) decreases in soil permeability through compaction, 2) increases in runoff volumes through vegetative changes, 3) and alterations in slope configuration due to landslides, faulting, or road and skid trail construction. Gullies also form abundantly in soft geologic formations i.e. Central Belt, where durable rock is not available for self-armoring and in unconsolidated colluvium or artificial fill.

Channel Disturbance and Recovery

Considerable documentation as presented in the NCWAP Gualala River Watershed Assessment show that landslides have adversely impacted the stream channels in the Gualala Watershed. It is clear that past land-use practices that were indifferent to stream health triggered many landslides and directly placed large volumes of sediment in the stream channels. Road and skid trial construction were the primary culprits. However, the Coast Ranges in general and the Gualala Watershed in particular are areas of naturally high background levels of landslide activity due to geologic and climatic conditions; i.e., steep slopes, weak rock, high rainfall, seismic shaking, and uplift. It is unknown (and well beyond the scope of this study) to what degree land use has accelerated natural erosion levels and how long the residual effects will last. *If deadlines permit, we can develop a rough sediment budget in our fluvial GIS.*

Heavy rainfall and high river flows are responsible for triggering many landslides and washing out roads. Storm damage occurs with or without land use. However, poor land use practices can increase the erosion and sediment load. In order to judge whether impacted streams are recovering from anthropogenic disturbance, such as past logging practices, it is necessary to understand the natural conditions that would constitute the pre-disturbance state. Review of a time series of historic aerial photos, dating back to the 1940's, shows that the storm damage related to 1964 flood was the most severe experienced in the watershed (Draft NCWAP Gualala River Watershed Assessment, 2001).

This report describes and maps much of the background geologic conditions, which both 1) define the sensitivity of an area to erosion and disturbance and 2) reveals the complexity of the long-term evolution of background conditions. Channel disturbance is also mapped and described. Although, in regards to historically active landslides and present stream channel sediment loads it may not be possible, in this study, to differentiate natural conditions from impacted conditions. A long term monitoring program could establish any trends toward "recovery", but that too is well beyond the scope of this study. The stream channel disturbance maps included with this report would serve as a valuable starting point for any such evaluation.

Roads are prone to fill and cutbank failure where built across active slides, steep slopes, and where they cross, or impinge on flood prone zones, or interrupt drainage. Diverted runoff from poorly drained roads may trigger large landslides.

In upslope areas, small natural streams evolve over hundreds and thousands of years and develop an armor formed by the lag deposits of rock within the channel. However where drainage is diverted to new areas, gullies form as un-armored soil is readily washed away. In the Gualala Watershed, legacy systems of roads and skid trails crisscross hillsides and re-arrange drainage. Often where the runoff flows down the road or skid trials deep gullies form and movement of larger landslides is triggered. Engineered fixes, such as the installation of ditches and culverts, has not always reduced erosion. Inside ditches divert runoff away from many small natural channels and concentrate the flow. The flow, often turbid, eventually discharges through a culvert; sometimes into undesirable areas where channels, if existent, have evolved to accommodate lower volumes of water and sediment. This also accelerates erosion.

Gualala Watershed Erosion and Sedimentation Damage

In response to the 1964 storm, sediment accumulated in many of the upper reaches –the transport reaches. Antecedent land use, such as in-stream landings and roads, elevated sediment loads. Some of the sediment blocked active channels; the rest become stored outside of the active channel. Subsequently, the accumulated sediment in the active transport channels generally has been dispersed downstream, where its fate is unknown. The rest has been variably vegetated and stabilized but may remain available for remobilization during sufficiently high flows. Channel armoring may resist bed remobilization.

The dispersed sediment was probably deposited in lower energy environments on the flood plains and in the stream channels. Fine sediment in these areas likely contribute to the increase in embeddedness and pool filling noted by other investigators.

Hillslopes that experienced mass wasting during the 1964 storm have generally revegatated. However, the south facing hillside above the South Fork of Fuller Creek is a glaring exception. This area was heavily vegetated with mature, second growth Douglas fir. The area was roaded and clearcut between the mid 1950's and early 1960's. This deforested area eroded severely during the 1964 storm. What makes this hillslope an exception is that it is still largely unvegetated and debris sliding remains very active. The reasons for this are unclear.

As described more thoroughly in the next section, aerial photos from 1984 and 1999/2000 were examined for evidence of channel disturbance. The 1984 photos were taken soon after the record wet year of 1983 (Goodridge, J., 1997). The 1999/2000 photos followed by 4-5 years the El Nino storms of 1995 (USGS, 1995). Channel disturbance is generally more widespread in the 1984 photos than in the 1999/2000 photos. This may indicate a general trend toward recovery from past disturbances. The apparent recovery may also be a consequence of milder storm conditions that allow recovery. Future damaging storms may interrupt or preclude recovery.

The plumbing of the Gualala River system is unique in many ways. In many areas during high flows tributaries back up and drop sediment, which is later abandoned and incised as flows diminish, at their mouths. This backwater effect was noted in several of the main tributaries and has formed a sediment mound in the active channel. During low flows, stream water percolates though the mound rather than flowing over it. It is unpredictable, at this time, whether future flows will reduce or build these mounds.

The river persists in transporting and storing sediment even at elevated loads. The residence time of excess sediment accumulated in transport reaches is relatively short and some recovery is apparent over decades; whereas, excess sediment accumulated in lower depositional reaches is hard to define and may remain much longer with only vague evidence of recovery. The Redwood Creek Watershed was similarly affected by 1964 flood and antecedent logging, was studied well beyond the scope of this assessment. There, long term channel surveys show sediment delivered during the 1964 flood are still stored in the middle and lower reaches (Oazki and Jones, 1998 and 1999). *Need to get this ref from Mark.*

General Stream Geomorphic Characteristics

Analysis of 1984, 1999, and 2000 aerial photos found that channel reaches exhibiting features of potential channel disturbance, including a lack of riparian, excess channel bars, multi-thread channels, channel bank erosion, shallow landslides adjacent to or blocking channels, etc., are often associated with areas of moderated-to-high landslide potential. From 1984 to 2000, the portions of channels mapped as potentially disturbed generally decreased slightly, although some reaches apparently had and increase in disturbance. Bank erosion and shallow landsliding associated with near-channel roads often showed signs of instability and erosion in both sets of photos.

Limited field reconnaissance found a good spatial correlation between the channel disturbance features identified on aerial photos and the on-the-ground evidence of instability. In general, channels mapped as excessively wide corresponded to stream reaches with abundant sediment deposits which appear to prevent riparian vegetation from re-establishing either because of continued removal by flood events or because the depth of sediment prevents shallow roots from obtaining sufficient water to become established. Channels in disturbed reaches were found to be generally narrower and more deeply incised than channels mapped stable reaches. These characteristics are consistent with observations of others (James, 1999; Madej and Ozaki, 1996) regarding the geomorphic changes as a channel tries to re-establish a stable configuration by eroding excess sediment.

Mapping of gullies observable on aerial photographs at a scale of 1:24,000 or smaller found good spatial correlation between gully formation and moderate- to high-landslide potential areas. Although these observations are likely biased by type and density of vegetation, gullies are best observed in grasslands and sparsely vegetated areas, suggesting that the occurrence of gullies has an underlying geologic trigger.

General stream geomorphic characteristics were evaluated using the 10-meter DEM to simulate the entire watershed drainage network. A DEM based network was produced assuming a minimum drainage area for a zero-order basin of 1 hectare. Comparison of DEM stream network with the USGS topographic contours and the digital orthophoto quads found the 1 hectare minimum area produced a reasonable representation of the drainages, although there is some misalignment of the smaller drainages with the contour crenulations. The stream order of USGS blue-line streams is higher for the DEM-based network than would be calculated from the USGS line work alone. A DEM-based network using a minimum drainage area of 10 hectares produces a drainage network similar to the USGS 1:24,000 topographic maps blue-line streams, but the smaller drainages are missed. The higher order simulated streams compared favorable with the USGS 1:24,000 blue-line stream network except where the angularity of the DEM network deviated at sharp bends. Network generated sub-basin boundaries generally agree with the CalWater boundaries except where CalWater boundaries are not drawn based on hydrologic characteristics, mainly at the planning watershed (pwsname) level.

Table 1 lists general watershed and stream geomorphic characteristics based on the DEM drainage network. Values in the table are based on the lowermost point in the named planning watershed (pwsname) and represent cumulative upstream values. Table 1 also includes estimates of bankfull stream geomorphology are made using regional equations developed by Rosgen and Kurz (January 2000) from USGS stream gage data on several north coast rivers. Stream gages used in the study are located on major rivers where upslope drainage area is greater than 28 square miles (18,000 acres). The channels studied included B, C and F Rosgen types with channel sediment size ranging from gravel to cobble (Rogen class types 3 and 4). The bankfull geomorphic channel characteristics listed in Table 1 should be considered approximate and are derived from relatively stable channel reaches. Geomorphic characteristics of reaches with high sediment deposition and/or variable channel hydraulics will likely differ from these values.

Geomorphic and Geologic Descriptions of Sub-basins

Mass Wasting Characteristics

North Fork Basin

The steepest topography and broadest valleys are found in the North Fork basin. The area is characterized by rectilinear, low ordered drainages underlain by the Coastal Belt of the Franciscan Formation. Preliminary interpretations suggest that this part of the Gualala watershed was uplifted more recently than the remainder. A series of NW trending strike-slip faults have offset drainages in a uniform manner. Although the formation of this region created steep slopes, the area is relatively more stable and coherent compared to the rest of the watershed. Steep, V-shaped, narrow, rectilinear fault controlled valleys characterize the upper reaches of the basin. A parallel network of faults creates a stream network with a simple zigzag pattern consisting of a high density of short, closely spaced drainages. Rosgen classes range from A++ to B types. Type A channels are characterized by “inherent channel steepness, high sediment transport potential, and relatively low in channel sediment storage capacity”. In eastern half of the NF basin, Central Belt mélange underlies prairies. Large areas of active earthflows and other forms of landsliding are abundant and contribute sediment to watercourses.

In lower reaches of the basin, streams generally meander through alluviated valleys that range from a couple hundred ft. to almost one thousand feet across within steep, V-shaped but flat-bottomed valleys. Streams in this area are characterized by "C" type Rosgen with "sinuous, low level relief, well developed flood plains built by the river, and characteristic point bars within the active channel". Continual sediment deposition and storage in this reach probably dates back millennia or more. The valley floors broaden downstream toward the San Andreas Fault. There is an abrupt steepening of stream grade where the river enters the San Andreas Fault Zone. An anomalous mound of sediment has formed immediately upstream of the confluence with the Little North Fork as is common in many areas. This sediment accumulation may be related to deposition caused by the slowing of the North Fork as it merges with flows of the Little North Fork. This frequently observed situation is informally known as a "back water effect". The active channel of the North Fork has incised into the mound of sediment, leaving much of the sediment stored on the flood plain. Historic reports show that parts of the North Fork has aggraded 4 to 6 ft. over a couple of decades. However, no information is available regarding the source or extent of the aggraded material.

The abundance of steep slopes, absence of moderate slopes, high drainage density, and high potential for debris flows/slides restricted "low impact siting and low maintenance construction" for roads and landings. Ridgeline and WLPZ alignments were the only alternatives to road construction across steep slopes. Roads on steep slopes generally are cut into and fills placed on active debris slide slopes. Steep areas subject to flashy, intense drainage that challenge watercourse crossings and high peak flows that erode beds and banks. Raveling of cutbanks along debris slide slopes has been noted to shed sediment into NF, Rockpile, Buckeye and their tributaries.

Rockpile Basin

Geologic conditions are very similar to the North Fork, except that topography is less steep and the main channel is narrower. A series of NW trending strike-slip faults have offset drainages in the middle and upper Rockpile basin. This created a zig-zag pattern with abrupt turns in the stream network. The valleys in these areas are steep, narrow, and V-shaped. Horsethief canyon especially characterizes this topography. Drainage gradients in the higher reaches of the basin are characterized by Rosgen classes ranging from A++ to B types, with the upper B-type more predominant.

Buckeye Basin

Of the three northern sub-basins of roughly equal size, the Buckeye basin contains the most moderate terrain compared to the North Fork and Rockpile. In the mid to upper reaches of Buckeye, stream channels cross and deflect along strike-slip faults creating abrupt zig-zags. Osser and Flat Ridge Creeks are two examples. CDF mapping found abundant landslides in the Buckeye basin following the 1964 storm as well as subsequent major storms. DMG mapping shows numerous historically active streamside failures occur all along its course. Many of these involve poorly maintained legacy roads DMG NCWP). For example, erosion along the Kelly Road has been a long standing concern with NCWQCB.

Fuller Creek

The NF and SF of Fuller Creek drain deeply dissected relic landslide terrain. The relic landslides may have formed during the Pliocene along the paleo-shoreline, with the possibility of having been submarine. The deep-seated relic slides appear stable. However, the slopes are very steep and shallow debris slides are common. Several debris flows and debris slides occurred within heavily logged areas during the 1964 storm.

Tombs Creek

This area, the Central Belt of the Franciscan Formation, is one of high concentration of landslides, many active.

House Creek

The gate on a 4-5' high dam on House Creek on Soper Wheeler property has been opened probably because the reservoir has been completely filled with bedload from upstream. Downstream of the dam the channel is incised to bedrock, probably due to the depletion of bed and suspended loads. In a few areas along House Creek, remnant bedrock terraces –capped with cobble sized alluvium- are found above the channel (as much as 1-5-20' in one area). Downstream of the dam, House Creek the bed changes dramatically from a shallow flat bottomed, fines-dominated condition to a bedrock terrace covered with cobbles coarse sands, and gravels. A large portion of the alluvium is out of the active channel. This terrace occurs approximately at the toe of a large active landslide. Some of the coarse material may have derived from the slide. The bedrock terrace may represent a localized uplift or tilting, perhaps due to deep seated forcing of the landslide against the bank. For example some slides move by rotational about a horizontal axis. So, in rotational slides the toe area may become somewhat elevated. However; no attempt has been made to test these hypotheses Continued use by cattle has trampled the banks in some areas and may adversely contribute to the nutrient load –algae was noted to be common in pools in House Creek.

Pepperwood Creek (Tributary to House Creek)

In the headwaters of Pepperwood (Oak Mountain), landsliding is especially abundant, active, and complex. Downstream in map sections 15 and 16 the stream cuts into a broad alluvial terrace that is almost 900 feet wide at the confluence with Jim Creek. Much of terrace material is outside of the active channel. This terrace and those along House Creek seem to be isolated remnants of former drainage patterns and may even be related to isolated fluvial deposits along the crest of Kings Ridge about a mile to the south and elsewhere in the uplift. And so it is uncertain whether the coarse and locally abundant alluvial deposits and bedload result solely from sediment transport within the current stream network from the abundant landslides in the headwaters or from a former system that has been deranged by faulting and uplift and no longer operates.

Upper South Fork Basin (Upstream from confluence with Wheatfield Fk.)

Most of the SF is an alluvial stream that mostly flows within the linear valley formed by San Andreas Fault. However, the upper reaches are incised to bedrock and occupy a parallel valley east of the San Andreas Fault. Large active earthflows are common along most the length of SF. Small (< 100 feet greatest dimension) historically active slides that delivered into SF are especially abundant from Russian Trough Spring and northward. From our limited observations the sediment production along the roughly parallel lengths of Marshall Creek and SF is similar. But unlike the Marshall Creek, the majority of the historically active, small landslides occur within the generally more stable Coastal Belt Franciscan rocks. These rocks presumably have been severely weakened by shearing within the San Andreas Fault Zone.

Marshall Creek

Marshall Creek drains an area where the Central and Coastal Belts of the Franciscan Formation have been complexly faulted and shuffled. Large active earthflows within the Central Belt rocks are common along most the length of Marshall. Small (< 100 feet in greatest dimension) historically active slides that delivered into Marshall Creek are especially abundant in the lower reaches where the stream crosses the weak rocks of the Central Belt Franciscan Formation.

McKenzie Creek

The McKenzie drains Kings Ridge, which is a small portion of a 4kmx8km area that was uplifted no later than the last 5 million years because of compression along the San Andreas Fault. See the geology report for explanation. Within this uplift, the upper two forks of McKenzie flow through parallel steep canyons flanked by debris slide slopes where the channels widen. The lower McKenzie narrows and flows southward across the uplift and joins Marshall. Numerous active earthflows occur along large portions of channels, even more abundant are dormant earthflows that potentially could be reactivated. In each of these landslide-impacted reaches, the channels widen.

Lower South Fork (Downstream of the confluence with Wheatfield Fork)

An active earthflow at Valley Crossing contributes sediment to stream. Many landslides dumped into this stream during the 1906 earthquake. Shallow landsliding as debris flows and debris slides is common.

Wheatfield Fork

The Wheatfield Fork basin is the largest subbasin in the Gualala Watershed. It is entirely underlain by Franciscan Formation. Although in many areas the Ohlson Ranch Formation overlies the Franciscan. Within the Franciscan Formation, the Central and Coastal Belts are interleaved along NW trending faults. Much of the basin was below sea level during the Pliocene. While submerged wave action planed off many of the ridges. These planed off ridges or terraces are apparent today as flat topped ridges, which generally have a veneer of marine sediments that compose the Ohlson Ranch Formation.

The Coastal Belt of the Franciscan Formation is bounded on the east and west by major strike-slip faults, the Tombs Creek Fault Zone and the San Andreas Fault Zone respectively. These and several strike-slip faults cut the bedrock in this basin. Multiple generations of lateral movement along these strike-slip faults have progressively disrupted and rearranged drainage and created vertical changes in the topography. The winding path of the Wheatfield Fork is 56 km long although it it only 24 km long as the crow flies. This is due to two parallel, NW oriented shutter ridges that form obstacles around which the river flows. The shutter ridges probably were progressively slid NW and/or uplifted into position along the San Andreas and Tombs Creek, and ancillary faults. The ridges shunt Wheatfield Fork drainage along their NW trending, east facing range fronts. More complex patterns of stream disruption due to faulting are evident in the eastern portion of the subbasin and are described in the geology report in the Appendix. The headwaters of the Wheatfield lie on the east side of the Tombs Creek Fault Zone within the Central Belt of the Franciscan Formation. Large earthflow complexes are abundant in this area. Large complexes of rockslides flank the ridges along the Tombs Creek and San Andreas Faults. The Ohlson Ranch Formation is poorly consolidated and is subject to landsliding along the edges of terraces or along incised drainages.

Channel Characteristics

North Fork Gualala Super Planning Watershed

Aerial photo interpretation of the North Fork Gualala planning watershed found overall levels of channel disturbance greater in the 1984 photos (WAC-84-C, 4-21-84) than the 1999/2000 photos (WAC–C-99CA, 4-13-99; WAC-00-CA, 4-2-00).

Doty Creek Planning Watershed

Aerial photo interpretation of the Doty Creek planning watershed found overall minor levels of channel disturbance in the 1984 photos. Most channel disturbance in this planning watershed was concentrated along Doty Creek where approximately 30 percent of the channel appeared disturbed and in an un-named tributary (S.11, T.11N., R.15W.) where approximately 50 percent of the channel appears disturbed. Overall there was a total of 27 small landslides in the 1984 imagery that appeared to deliver sediment into the channels. Eleven of those slides were adjacent to Doty Creek and 5 on the un-named tributary. Eleven more slides were scattered through the planning watershed.

Aerial photo interpretation of the Doty Creek planning watershed found overall conditions of the channels improved in the 1999/2000 photos. No major channel disturbances are visible on these recent photos and four landslides were mapped as delivering sediment to the channels. Three slides are along the upper reaches of Fleming Creek and one on Doty Creek are observed in 1984 photos.

Robinson Creek Planning Watershed

Aerial photo interpretation of the Robinson Creek planning watershed found overall levels of channel disturbance greater in the 1984 photos (WAC-84-C, 4-21-84) than the 1999/2000 photos (WAC–C-99CA, 4-13-99; WAC-00-CA, 4-2-00). In the 1984 images, approximately 75 percent of the North Fork Gualala River within the Robinson Creek planning watershed appeared disturbed with enlarged and numerous bars and lack of riparian vegetation. Seven landslides are mapped as delivering to the lower reach of main channel or to adjacent minor tributaries. By 1999/2000, the North Fork Gualala channel appears to have improved with disturbance between 50 and 75 percent, but channel bars appear smaller. Six delivering landslides are mapped in the lower reach, four at locations mapped in 1984.

Approximately 75 percent of the lower portion of Robinson Creek appeared disturbed in the 1984 photos with numerous longitudinal bars and cutoff chutes. Three landsides were mapped as delivering sediment into the channel. In 1999/2000, Robinson Creek improved having approximately 30 percent of the channel showing signs of disturbance, but the number of delivering landslide increased to 7, most were at location different from 1984.

Dry Creek had at least 80 percent of the channel disturbed in the 1984 images upstream from the junction with the North Fork Gualala to the confluence of Johnny Woodin and Fisher ridges (S. 6, T.11N., R.14W.). The upper reach of Dry Creek above this point is also disturbed at least 80 percent with 13 landslides mapped as delivering to the channel. On the north side of Fisher Ridge approximately 50 percent of the channel is disturbed and seven channel delivering landslides are mapped. Between Johnny Woodin and Brandt ridges an un-named tributary has approximately 30 percent channel disturbance with 11 landslides mapped as delivering to the channel. In the 1999/2000 images, the upper reach of Dry Creek improved to approximately 50 percent of the channel showing disturbance with 13 landslides, 5 of which are mapped in 1984. The lower reach also improved to approximately 50 percent of the channel showing disturbance and 8 delivering landslides. The un-named tributary between Johnny Woodin and Brandt ridges has less than 25 percent disturbance with 6 delivering landslides.

Aerial photo interpretation of McGann Gulch 1984 images found greater than 80 percent of the main channel disturbed with 9 delivering landslides. By 1999/2000, channel disturbance is less than 50 percent with most occurring in the lower reach. Four landslides deliver to McGann Gulch, all were also delivering in 1984.

Stewart Creek Planning Watershed

In the 1984 images, at least 80 percent of the North Fork Gualala River within the Stewart Creek planning watershed appeared disturbed with enlarged and numerous bars, cutoff chutes and a lack of riparian vegetation. Thirty-two landslides are mapped as delivering to the North Fork Gualala main channel or to adjacent minor tributaries. By 1999/2000, the North Fork Gualala channel appears to have improved to where 50 to 70 percent of the main channel appears disturbed. Thirty-four delivering landslides are mapped, 14 of which are at location mapped in 1984 images.

Stewart Creek appears to have at least 90 percent of the channel disturbed in 1984 images with 6 landslide delivering to the channel. By 1999/2000, the stream improved to where approximately only one-third of the upper reach appeared disturbed. Six delivering landslides were mapped in 1999/2000.

Billings Creek Planning Watershed

In the 1984 images, approximately 25 percent of the lower and 75 percent of the upper reaches of Billings Creek appeared disturbed with enlarged bars, multi-thread channels, bank erosion and lack of riparian vegetation. By 1999/2000, in the lowermost reach approximately 10 percent appeared disturbed. In the middle reach, 50 percent of the channel appeared disturbed with 7 delivering landslides. The upper reach appeared to improve with less than 50 percent of the reach disturbed and 6 delivering landslides.

Robinson Creek (a second creek) appeared to have approximately 70 percent channel disturbance in the 1984 images. Some improvement occurred by 1999/2000 with approximately 50 percent disturbance. Palmer Creek had minor sections of disturbance with 6 delivering landslides mapped on the adjacent slopes.

Rockpile Super Planning Watershed

Aerial photo interpretation of the Lower Rockpile Creek planning watershed found overall levels of channel disturbance greater in the 1984 photos (WAC-84-C, 4-21-84) than the 1999/2000 photos (WAC–C-99CA, 4-13-99; WAC-00-CA, 4-2-00).

Lower Rockpile Creek Planning Watershed

In the 1984 images, at least 80 percent of the lower reach of Rockpile Creek within the planning watershed appeared disturbed with enlarged and numerous bars, braided reaches, and a lack of riparian vegetation. Thirteen landslides were mapped along the reach as delivering sediment to the channel in 1984. By 1999/2000 there is some improvement in the channel conditions as 50 percent of the channel reach appears disturbed in the imagery. Three delivering landslides are mapped along the main reach and 12 slides are mapped in an un-named tributary located in Section 28, Township 11 North, Range 14 West.

Redrock Planning Watershed

Rockpile Creek in the Redrock planning watershed is also characterized by a high percentage, greater than 80 percent, of apparent channel disturbance in the 1984 imagery. Five delivering landslides are mapped along the main channel. An un-named tributary (S.22, T.11N., R.14W.) also has approximately 25 percent channel disturbance with 3 adjacent landslides likely delivering sediment to the channels.

By 1999/2000 there was some improvement in the channel disturbance characteristic in Rockpile Creek, resulting in 50 to 75 percent apparent disturbance. Four delivering landslides are mapped. The un-named tributary of section 22 showed an increase in disturbance indicators with approximately 50 percent of the channel disturbed and an increase to 13 delivering landslides.

Middle Rockpile Creek Planning Watershed

Approximately 75 percent of the middle reach of Rockpile Creek appeared disturbed in the 1984 imagery with bank erosion common, particularly in Section 12, Township 11 North, Range 14 West. Fourteen landslides were mapped as delivering sediment to the channel and adjacent tributaries. Two other un-named tributaries along the southeastern flank of McGuire Ridge showed signs of significant channel disturbance in Sections 14 and 15, Township 11 North, Range 14 West. These un-named tributaries appear to have at least 80 percent of the reach disturbed with 7 adjacent landslides delivering sediment.

By 1999/2000 disturbance in the middle reach of Rockpile Creek is reduced to approximately 50 percent with 10 delivering landslides. The two un-named tributaries in section 14 and 15 have also improved with disturbance approximately 25 percent of the reach and 2 delivering landslides.

Approximately 75 percent of the channels in Horsethief Canyon appear disturbed in the 1984 imagery with one delivering landslide. By 1999/2000, the upper reach improved and only 25 percent appears disturbed, most in the lower portion of the reach. However, 3 delivering landslides are mapped adjacent to the main channel or tributaries.

Upper Rockpile Creek Planning Watershed

Approximately 50 percent of upper Rockpile Creek channel shows characteristics of channel disturbance in the 1984 imagery. Twenty-seven landslides are mapped as delivering sediment to the channel. By 1999/2000 the overall disturbance is still approximately 50 percent, but the upper reach of the is less disturbed and the number of delivering landslide has decreased to 15.

Buckeye Super Planning Watershed

Aerial photo interpretation of the North Fork Gualala planning watershed found overall levels of channel disturbance greater in the 1984 photos (WAC-84-C, 4-21-84) than the 1999/2000 photos (WAC–C-99CA, 4-13-99; WAC-00-CA, 4-2-00).

Little Creek Planning Watershed

Buckeye Creek in the Little Creek planning watershed is characterized by approximately 80 percent apparent channel disturbance in the 1984 imagery. Bank erosion is common in the reach upstream of Little Creek. Seventeen delivering landslides are mapped. Little Creek has approximately 80 percent apparent channel disturbance in the 1984 imagery with some areas of bank erosion and 14 delivering landslides.

By 1999/2000, Buckeye Creek has recovered some with approximately 50 to 75 percent channel disturbance and 12 delivering landslides. Bank erosion continues upstream of the junction with Little Creek. Little Creek has recovered more with approximately 25 percent of the channel having disturbance characteristics and 6 delivering landslides mapped.

Grasshopper Creek Planning Watershed

The 1984 imagery of Grasshopper Creek planning watershed shows that Buckeye Creek between Grasshopper and Soda Springs creeks is approximately 25 percent disturbed with some areas of bank erosion and two delivering landslides. By 1999/2000 the area increase in apparent disturbance to less than 50 percent, continued bank erosion and seven landslides delivering sediment to the channel.

In Francini Creek, the 1984 imagery shows at least 90 percent channel disturbance with 17 delivering landslides. In the 1999/2000 imagery some improvement is evident with approximately 50 percent of the reach apparently disturbed reach with 2 delivering landslides.

The lower reach of Grasshopper Creek is approximately 50 to 75 percent disturbed in the 1984 imagery with 3 delivering landslides. By 1999/2000 signs of apparent channel disturbance are less than 25 percent of the reach, mostly in the upper portion. Four delivering landslides are mapped from the 1999/2000 images.

Soda Springs Creek shows approximately 25 percent apparent channel disturbance and 2 delivering landslides in 1984 imagery. In the 1999/2000 images, disturbance characteristics are seen on less than 10 percent of the reach, but 4 delivering landslides are mapped.

Harpo Reach Planning Watershed

In the 1984 imagery, the North Fork of Harpo Reach planning watershed shows approximately 10 percent apparent disturbance most within a mile upstream of the junction with Buckeye Creek. Some additional disturbance is mapped along an un-named tributaries in Sections 29 and 30, of Township 11 North, Range 13 West. Ten delivering landslides are mapped across this planning watershed.

By 1999/2000 the un-named tributaries in Section 29 continue to show disturbance while the section of North Fork above Buckeye Creek appears to have recovered. A new portion of Buckeye Creek for approximately one mile below the North Fork Osser planning watershed boundary now has signs of channel disturbance. Other areas of the watershed show general improvement in channel conditions.

Flat Ridge Creek Planning Watershed

The lower reach of Buckeye Creek below Flat Ridge Creek is generally disturbed up to 75 percent of the reach in the 1984 imagery and 4 delivering landslides are mapped. Above the junction with Flat Ridge Creek, the 1984 imagery shows less disturbance in Buckeye Creek with up to 50 percent impacted and 8 delivering landslides.

By 1999/2000 the portion of Buckeye downstream of Flat Ridge Creek has improved with approximately 20 percent disturbed and 7 delivering landslides. Above Flat Ridge Creek, Buckeye Creek continues to have approximately 50 percent disturbed reach, but the disturbed areas are a higher percentage in the downstream portion.

Flat Ridge Creek shows approximately 70 percent disturbance in the 1984 imagery and 10 delivering landslides. By 1999/2000 the reach has generally recovered from the disturbance.

North Fork Osser Creek Planning Watershed

In the 1984 imagery, Roy Creek shows less than 10 percent of the channel disturbed with 2 delivering landslides near the junction with Osser Creek. In the 1999/2000 images, channel disturbance appears to increase to less than 25 percent. Osser Creek has approximately 10 percent disturbance and 4 delivering landslides in the 1999/2000 images.

Wheatfield Fork-Lower Wheatfield Fork Super Planning Watershed

Annapolis Planning Watershed

In the 1984 imagery at least 80 percent of Wheatfield Fork of Gualala River appears disturbed with large lateral bars common, bank erosion in several areas, and 25 delivering landslides. By 1999/2000 there is some reduction in the size of the bars in the middle reach, less bank erosion, and 9 landslides, three are in the same location as in the 1984 imagery.

Flat Ridge Creek Planning Watershed

In the 1984 imagery, Fuller Creek below the North Fork/South Fork junction has less than 80 percent disturbed with several areas of multithread channel, 5 delivering landslides are mapped. Sullivan Creek appears disturbed for approximately one-half mile upstream of Fuller Creek. In the 1999/2000 imagery less than 30 percent of the lower portion of Fuller Creek is disturbed, but 13 delivering landslides are mapped.

The North Fork of Fuller Creek appears to be less than 50 percent disturbed in the 1984 imagery, mostly in the upper reaches, six delivering landslides are mapped. By 1999/2000 less than 25 percent of the upper reach is disturbed and 9 landslides are mapped.

The South Fork of Fuller Creek is at least 80 percent disturbed in the 1984 imagery with braided channels common, and 39 delivering landslides. By 1999/2000 less than 50 percent of the channel appears disturbed, some bank erosion associated with a near channel road and 30 delivering landslides are mapped.

Tobacco Creek Planning Watershed

In the 1984 imagery, Wheatfield Fork in the Tobacco Creek planning watershed is at least 75 percent disturbed with bank erosion along the outside bends common, and 37 delivering landslides. By 1999/2000 less than 50 percent of the channel appears disturbed. Bank erosion on the outside of bends continues, 29 delivering landsides are mapped, 15 at locations mapped from the 1984 images.

Tobacco Creek has approximately 30 percent channel disturbance in the 1984 imagery with braided and incised channels common. An un-named tributary in Sections 22 and 27, Township 10 North, Range 13 West has approximately 50 percent disturbance and 5 delivering landslides in 1984 imagery. By 1999/2000, less than 20 percent of Tobacco Creek appears disturbed, most in the lower reach, and 3 delivering landslides are mapped in the upper reach area.

Haupt Creek Planning Watershed

In the 1984 imagery, approximately 30 percent of Haupt Creek appears disturbed mostly in Sections 9 and 12 of Township 9 North, Range 13 West, and 4 delivering landslides are mapped. By 1999/2000, less than 30 percent is disturbed with the disturbance shifting downstream to the lower half of the channel, mostly in Sections 4, 9 and 10, Township 9 North, Range 13 West. Twenty-one delivering landslides are mapped from the 1999/2000 imagery.

Wheatfield Fork-Hedgepeth Lake Super Planning Watershed

House Creek Planning Watershed

In the 1984 imagery, channel disturbance ranged from 25 to 50 percent with 2 delivering landslides mapped along House Creek. By 1999/2000, less than 25 percent of House Creek appears disturbed.

Pepperwood Creek Planning Watershed

Pepperwood Creek appears to have approximately 50 percent channel disturbance in the 1984 imagery and 25 to 50 percent in the 1999/2000 imagery. Two delivering landslide are mapped from the 1999/2000 imagery.

Danfield Creek has approximately 50 percent channel disturbance in the 1984 imagery and 5 delivering landslides. In the 1999/2000 imagery, approximately 30 percent of the channel is disturbed.

Britain Creek Planning Watershed

The upper reach of House Creek above Pepperwood Creek and Pepperwood Creek in Sections 3, 4 and 5, Township 9 North, Range 12 West, both appear to have 50 percent disturbance in the 1984 imagery. The amount of channel disturbance in 1999/2000 imagery is similar to 1984 with addition of 2 delivering landslides.

Wheatfield Fork-Walters Ridge Super Planning Watershed

Wolf Creek Planning Watershed Planning Watershed

In the Wolf Creek planning watershed, Wheatfield Fork channel disturbance ranges from 25 to 50 percent in the 1984 imagery with 18 delivering landslides mapped. In the 1999/2000 imagery less than 25 percent of Wheatfield Fork within Wolf Creek planning watershed appears disturbed and 10 delivering landslides are mapped, 8 upstream of the confluence with Tombs Creek.

In the 1984 imagery, less than 25 percent of Wolf Creek appears disturbed, mostly in the upper reach, and 4 delivering landsides are mapped. By 1999/2000 less than ten percent of the channel is disturbed with 3 delivering landslides.

Approximately 50 percent of Spanish Creek appears disturbed in the 1984 imagery mostly upstream of the confluence with Buzzard Creek, 3 delivering landslides are mapped. By 1999/2000 less than 25 percent of Spanish Creek is disturbed above the junction with Buzzard Creek.

Tombs Creek Planning Watershed Planning Watershed

Fifty to seventy-five percent of the Tomb Creek appears disturbed in the 1984 imagery with 10 delivering landslides. In the 1999/2000 imagery less than 25 percent of the channel is disturbed, mostly in Section 17, Township 10 North, Range 12 West, and 4 delivering landslides are mapped.

Buck Mountain Planning Watershed Planning Watershed

In the 1984 imagery, the Wheatfield Fork in Buck Mountain planning watershed has less than 75 percent disturbed channel, mostly in the lower reach, and eleven delivering landslides. By 1999/2000 the channel disturbance is less than 30 percent and seven delivering landslides are mapped.

Marshall Creek Super Planning Watershed

Middle South Fork Gualala River Planning Watershed

In the 1984 imagery, channel disturbance in the South Fork Gualala River ranged from 50 to 75 percent with 26 delivering landslides. By 1999/2000, the length of channel disturbance had not changed significantly and 41 delivering landslides are mapped. Wide lateral bars and bank erosion are common.

Upper South Fork Gualala River Planning Watershed

Channel disturbance in the 1984 imagery ranges from 25 to 50 percent with 16 delivering landslides. In the 1999/2000 imagery approximately 25 percent of the channel is disturbed and 19 delivering landslides are mapped.

Lower Marshall Creek Planning Watershed

In the 1984 imagery, the lower reach of Marshall Creek has 50 to 75 percent channel disturbance. In 1999/2000 imagery, approximately 50 percent of the channel is disturbed downstream of McKenzie Creek and 10 delivering landslides are mapped.

Upper Marshall Creek Planning Watershed

McKenzie Creek is greater than 50 percent disturbed in the 1984 imagery with three delivering landslides. In the 1999/2000 imagery, less than 25 percent appears disturbed with 2 delivering landslides.

Lower South Fork Gualala River Super Planning Watershed

Big Pepperwood Creek Planning Watershed

In the 1984 imagery, less than 25 percent of Big Pepperwood Creek and tributaries appear disturbed with 16 delivering landslide mapped. South Fork Gualala commonly has large lateral bars with less than fifty percent of the channel appearing disturbed. By 1999/2000 Big Pepperwood Creek has less than 25 percent disturbed channel with 12 delivering landslides. The South Fork Gualala channel bars near Big Pepperwood Creek appear to be reduced in size.

Mouth of Gualala River Planning Watershed

In the 1984 imagery approximately 50 percent of the South Fork of the Gualala River in the Mouth of Gualala River planning watershed appears to have large lateral and mid-channel bars, especially at tributary with Wheatfield Fork. By 1999/2000 the size of the bars appears smaller in the imagery, more vegetation on bars, but the Wheatfield Fork confluence still appears impacted. Excess bars appear at the mouths of Wheatfield, Buckeye and Rockpile creeks. Field reconnaissance found that sediment build up at the mouth of the major channels causes surface water to flow subsurface for several hundreds feet upstream from Gualala River.

Methodology

Typical tasks making up the mapping process included literature review, site reconnaissance, and mapping. The methods are described in more detail in the appendix of the NCWAP Methods Manual.

Geologic and Geomorphic Base Layers in the GIS

A geologic base map, a landslides inventory map, and a landslide potential map were developed. Limited field studies were an important component in the creation of all three of these. The geologic base is a digital compilation of reference maps modified based on interpretations from aerial photo analysis and fieldwork. Topographic bases included U.S. Geological Survey 7.5' topographic maps, digital orthophotoquads (DOQ), and digital elevation models (DEM) with a 10-meter or better resolution. The landslide inventory map consists of landslides derived from reference maps, literature review, aerial photo analysis, and field studies. The landslide potential map was primarily derived from spatial and statistical analysis.

The second step in map production involved identifying and resolving any gaps or inconsistencies in the data. Field studies and aerial photo interpretation were conducted to verify and augment the existing data. As new data was being compiled, it was added to the GIS and the draft map.

Field Studies for Data Verification and Collection

This was a reconnaissance level, remote sensing program. However, some on-site field verification was conducted to provide a reasonable basis for extrapolation and generalizations. Limited field studies to supplement aerial photograph interpretation and mapping were performed to confirm interpretations and improve the capture and analysis of data. The accuracy of data (i.e., maps, GIS layers) borrowed from other sources was scrutinized in the field. Once a set of aerial photos were interpreted and initial draft landslide and geology maps were created, ground-truthing was conducted to confirm or clarify interpretations. Ground-truthing was limited due to time and access constraints.

Geologic Map

The geologic base map (described above) was refined as needed during fieldwork and remote sensing. The geologic map shows the locations of major lithologic units and geologic structures and describes the general rock types and their engineering properties as related to slope stability. The geologic map was produced in accordance to the conventions and nomenclature established by DOC/DMG's Regional Geologic and Hazards Mapping Program.

Landslides and Geomorphic Features Related to Landsliding Map

The vast majority of the geologic and geomorphologic interpretations were made through the examination of multiple series of stereo-paired aerial photographs through a mirrored stereoscope. A separate GIS layer was produced for each set. The data derived from the aerial photos was incorporated and is stored in the GIS. The data was transferred through either direct "heads-up" digitizing on screen, or transferred to mylar overlays and then scanned or digitized. Mapped landslides and geomorphic features were defined as indicated in the Methods Manual. Two sets of aerial photos were reviewed for the Gualala River watershed assessment. Back and white aerial photos from 1984 were reviewed for the entire watershed at a nominal scale of 1:31,500. Back and white aerial photos of the Mendocino County portion of the watershed that were taken in 2000 and color aerial photos of the Sonoma County portion taken in 1999 were combined into a single photo set with a nominal scale of 1:20,000. Time constraints prevented the review of additional photo sets

Landslide Potential Map

Once relevant relationships between geology and landsliding were recognized, a landslide potential map was created in the GIS. The landslide potential map was compared with the slope maps, landslide density thematic map, and other available slope models for important variations. Any important variations were interpreted.

The relative landslide potential was defined and illustrated in five categories from 1 (most sable) to 5 (least stable). Additional modifiers, which supplement the primary definitions, were added as relevant.

The assignment of the categories was an interpretative exercise and was based on relations drawn from the Landslide and Geomorphic Features Related to Landsliding Map, statistical analysis, and general field observations. The metadata documents the details of the ranking process.

The landslide potential map was produced at a scale of 1:24,000, the same as the landslide inventory map. The landslide potential map was constructed as an individual GIS layer.

Fluvial GIS Maps and Database

There are six fluvial mylar overlays produced for each watershed. Each overlay will contain a specific type of data, which may include polygons, lines and points in each overlay. Some of the features are placed in their own overlay to facilitate more rapid digitization or because the method or source on data differ. The six overlays are described below with the accompanying database, as needed.

1. Stream Disturbance Overlay

The stream disturbance overlay has two purposes that are interlinked. First, the overlay is intended to capture features that indicated disturbances within or directly adjacent to the channel and sediment sources in the active channel (eroding banks). Second, the overlay will map sediment stored within the active channel, channel below the 5-year flood stage.

2. Gullies Overlay

The gullies overlay is done separate from the stream disturbance because they are generally mapped in upslope areas rather than within a well defined stream channel. It is important to document active sediment source areas whenever they can be positively identified and with multiple year mapping define patterns of surface erosion.

3. Alluvial Contacts Overlay

The alluvial contacts overlay contains polygon boundaries of mapable alluvial stream units. These units are associated with the stream/river network and define those Quaternary units not already mapped by the landslide group's geologic compilation. These mapped units will be substituted into the geologic map once they are field checked.

4. Channel Classification, Rosgen types

The channel classification overlay has identified the channel types based on reconnaissance interpretation of the Rosgen type. The overlay is developed from a quadrangle scale base map that has the orthophoto quad, topographic contours and 1:24,000 blue line stream drainage network. The stream drainage network has been color coded for gradient based on the Rosgen class gradient breaks, <0.1%, 0.1 – 1%, 1 – 2%, 2 – 4%, 4 – 10%, >10%. The stream channel network has also be subdivided based on changes in sinuosity and valley width. Valley width is based on estimates of bankfull width derived from regional hydraulic geometry regression curves.

5. Watershed Characteristics Overlay

The watershed characteristics overlay contains general geomorphic information on the watershed at specific points along the 1:24,000 blue line stream network. The data are generally taken from the RiverTools analysis or calculated from that data. Fields in the database are both cumulative for the entire watershed above a point and specific to the sub-watershed adjacent to the data point. Hydraulic geometry relationships are estimated for each point using regression equations based on upslope drainage area.

6. Channel Data Sources Overlay

This overlay contains point locations for monitoring stations, data gathering locations, measured sections locations, natural structures and other restrictions to fish migration. The database also contains graphics and images on the data sites.

Limitations

Limited aerial photo coverage does not bracket temporal distribution of important watershed events, which may not be evident in photos taken years after the fact.

This project consisted of a reconnaissance level review of two sets of aerial photographs. The photos were taken in 1984 and 1999/2000. Mapping was conducted at a scale of 1:24,000 and covers the entire watershed. At this scale, the detection of features smaller than 100 feet in greatest dimension is poor.

Detailed site level mapping of landslides and sediment delivery were conducted by outside parties in various portions of the watershed; however, time and staffing constraints prevent evaluation of that data.

Existing geologic mapping of the RockPile Creek subbasin is limited to the CDMG 2-degree sheet. The presence and location of geologic features in this area were inferred from surrounding areas where more detailed mapping was available.

Due to access, time, budget, and staffing constraints; field checking of interpretations was extremely limited.

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